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Trade-offs and synergies in the ecosystem service demand of urban brownfield stakeholders

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ABSTRACT

Brownfield site redevelopment presents an opportunity to create urban green spaces that provide a wide range of ecosystem services. It is important, therefore, to understand which ecosystem services are demanded by stakeholders and whether there are trade-offs or synergies in this demand. We performed a quantitative survey of ecosystem service demand from brownfield sites that included all major stakeholder groups. Results showed that there was a strong trade-off between demand for services related to property development (e.g. ground strength and low flood risk) and all other services, which were linked to vegetated sites. There was a secondary, but weak, trade-off between demand for services of more 'natural' vegetated sites (e.g. with a biodiversity protection role) and those linked to aesthetics and recreation. Stakeholders with a strong preference for biodiversity protection formed a distinct group in their ecosystem service demands. While a 'development' vs 'green space' trade-off may be unavoidable, the general lack of strong trade-offs in demand for other services indicated that the creation of multifunctional greenspaces from former brownfield sites would be desirable to most stakeholders, as long as these are biophysically possible.

1. Introduction

Green spaces are increasingly recognised as a critical component of healthy and liveable human environments (Amati and Taylor, 2010; Benedict and McMahon, 2006). With ongoing global growth in the scale and complexity of urban areas and a desire to reduce urban sprawl, comes increasing pressure on the development of open space within cities (Dallimer et al., 2011; Haaland and van den Bosch, 2015; Seto et al., 2012). This makes it particularly important to understand the ways in which spaces can be kept or made green managed to promote sustainable development while ensuring environmental protection and the delivery of multiple ecosystem services (Chan et al., 2012a; Gaston et al., 2013; Keeler et al., 2019; Matsuoka and Kaplan, 2008; Riechers et al., 2016). The ability of ecosystems to simultaneously deliver multiple ecosystem services is referred to here as ecosystem service multifunctionality (Manning et al., 2018).

In this study we examined the ecosystem service 'demands' (which we define as 'the level of service provision desired by people' (Maron et al., 2017) of a range of urban stakeholder groups in relation to urban brownfield land. We use the UK National Planning Policy Framework definition of brownfield land i.e. 'land which is or was occupied by a permanent structure, including the curtilage of the developed land… and any associated fixed surface infrastructure' (National Planning Policy Framework, 2012 (Annex 2)) (Ministry of Housing, Communities & Local Government, 2018). This definition should be familiar to many of the professional stakeholders in this survey. UK based respondents, that the following analysis focuses on, work with land governed by the National Planning Policy Framework. It excludes land under agricultural and forestry constructions, mineral extraction sites, restored landfill, residential gardens, parks, recreation sites and allotments. Brownfield land area is growing globally, especially in 'shrinking cities' experiencing post-industrial decline such as Chicago and Leipzig (Herrmann et al., 2016; LaCroix, 2010). Due to the diverse nature of their land use and history, abandonment and redevelopment, brownfield areas often form unique open green spaces that are important for ecosystem service provision, including habitat for biodiversity and healthy environments for recreation (Mathey et al., 2015). Their transitional state primes them for a range of future land uses, such as the conservation of urban biodiversity,

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the creation of 'wilderness' areas (e.g. de Sousa, 2003; Harrison and Davies, 2002; Kowarik, 2018; Scott et al., 2016; Zefferman et al., 2018), or new urban developments. Brownfield sites can provide scope for 'engineered' solutions, in which soils and vegetation are intentionally remediated or managed to deliver specific services as part of ongoing site development (Jorat et al., 2020; Perring et al., 2013; Renforth et al., 2011; Sousa, 2006). This breadth of opportunity means it is likely that trade-offs will occur between the services demanded from brownfield sites by different stakeholder groups.

Challenges in developing and managing multifunctional urban spaces can emerge if there are trade-offs in ecosystem service supply (i.e. the capacity of an ecosystem to provide a given ecosystem service (Maron et al., 2017), meaning that not all of the services demanded by the stakeholder community are delivered. Such trade-offs can emerge from either differences in expressed demand between stakeholder groups, as different groups prefer to manage the site to deliver particular services, potentially at the expense of others, or biophysical limitations in ecosystem service supply, e.g. woody or grassy vegetation both promote some services but diminish others (de Groot et al., 2010; Hansen and Pauleit, 2014). Whether the elimination of these trade-offs is achievable, and whether the barriers are human or biophysical, often remains unknown (Bennett et al., 2009; Martín-López et al., 2012; Torralba et al., 2018). Therefore, identifying whether trade-offs occur at the supply or demand level, or at both, is key to identifying strategies which minimise trade-offs and possible conflicts. Eliciting and understanding the values and preferences of urban stakeholder groups is a rapidly developing field of study (Chan et al., 2012a,b; Jacobs et al., 2016; Primmer and Furman, 2012) and practice, particularly when allied with developments in participatory urban planning and decision-making (Hein et al., 2006; Lo and Jim, 2012). However, there is still a lack of understanding around how strongly different values and preferences are held, expressed or traded-off against one another. Here we provide an initial insight into patterns of demand, by investigating how different people view the relative importance of ecosystem services that can be provided by the brownfield environment, such as flood mitigation, carbon storage and recreation (Albert et al., 2014; Bolund and Hunhammar, 1999; Matsuoka and Kaplan, 2008). We focus on understanding the degree of synergy and trade-off in demand for multiple ecosystem services across a range of stakeholders in the UK, using a quantitative survey to investigate these views.

2. Materials and methods

This research was conducted as part of the SUCCESS (Sustainable Urban Carbon Capture: Engineering Soils for Climate Change) project, which built upon existing work (Manning and Renforth, 2013; Washbourne et al., 2012; Washbourne et al., 2015) to determine the extent to which urban brownfield soils could capture and store carbon. The SUCCESS project aimed to determine the performance of brownfield soils to act as a carbon sink (Jorat et al., 2020), as an element of multifunctional urban landscapes, and to consider practical and policy implications of managing land for carbon capture and storage alongside other ecosystem services.

In the first phase of the project, urban ecosystem services and disservices provided by brownfield sites were identified via stakeholder consultation in two workshops held in Newcastle upon Tyne, United Kingdom in October 2015 and October 2016. A total of 22 local stakeholders attended these workshops, including representatives from the full range of sectors involved in the development and/or remediation of brownfield land, including housing developers, local authorities, environmental NGOs, utilities companies, and engineering and ecological consultants. A provisional list of ecosystem services was developed by the project team, based on a preliminary literature review and experience of brownfield sites, and provided to the stakeholders, which they collaboratively expanded to ensure that all services they deemed important were listed. Both services and disservices were included; for example, some stakeholders interested in property development perceived the presence of certain protected species as an ecosystem disservice as this precluded development. Using stakeholder feedback, the services and disservices listed were then classified into five broad categories of service that were related to broad types of benefit and frequently demanded together. In some cases, these categories mixed elements commonly defined as provisioning, supporting, regulating or cultural services (Millennium Ecosystem Assessment, 2005). The categories were: recreation and education (cultural services); environment and climate (regulating and cultural services); food, energy and other plant products (provisioning and cultural services); nature and wildlife (supporting and cultural services); suitability for development (regulating services). This last category included services and disservices driven by ecosystem properties that influence property development, e.g. flood risk and ground strength.

In the second phase, an online survey was sent to a range of urban stakeholders working in the following sectors and disciplines: (i) industry (construction, engineering, minerals, quarrying, transport, housing, land development, energy); (ii) ecology and environment; (iii) landscape design and architecture; (iv) local government; (v) academia and (vi) those who classified themselves as general public or otherwise outside of the stated groups. The primary aim of this survey was to quantify the relative importance of different ecosystem services (demand) to a broad range of different brownfield stakeholder groups, with the intention of using these scores as weightings in ecosystem service multifunctionality measures (Manning et al., 2018). The survey was created in Jisc Online Surveys (formerly BOS). Respondents were asked to rate the importance of each category of service (Table 1) from the perspective of their employment sector, unless a member of the general public, according to a Likert scale (Importance rating 1–5, where 1 = Extremely Unimportant, 2 = Unimportant, 3 = Neutral, 4 = Important, 5 = Extremely Important). If an ecosystem services category was scored '3' or higher, Likert scores for specific services in this category were also requested. If the ecosystem service category was given a score of 1 or 2, the specific services in this category were given a score of 0 (Table 1). Open text responses were invited at the end of the questionnaire, where respondents could include comments and list other important services that they felt had not been captured. All additional services listed at this stage could be classified within the existing scheme.

The introduction to the survey stated that: "The SUCCESS project is investigating the capacity of previously developed vacant urban land (known as 'urban brownfield' land) to capture CO_2 from the atmosphere and store it in the soil in mineral form as calcium carbonate. This carbon capture process is one of many potential benefits (or 'ecosystem services') that could be provided by urban brownfield soils and this survey is designed to help us understand how people from different sectors value these different benefits". The respondents to the survey were, therefore, exposed to a particular framing within which responses were elicited, though the questions themselves were broad-based and related more generally to urban brownfield sites. The survey was circulated via targeted email to contacts from a wide range of sectors, who were known to the project team. They were asked to pass the invitation on to other relevant colleagues in a 'snowball' sampling approach. The survey was also promoted at various stakeholder events and via social media (Facebook, Twitter) and professional networks (ResearchGate, Linkedin).

The survey was live between 6th May 2016–29th November 2017. When closed it had received 201 full responses. These data were then constrained for this analysis to contain only respondents currently based in the UK, n = 140, to ensure comparability in the context of the National Planning Policy Framework. The breakdown of responses in the UK subset across the different stakeholder groups identified was: Industry = 26, Ecology and environment = 51, Landscape Design and architecture = 9, Local Government = 18, Academic = 34, General Public (greenspace users) = 30. Note that the total here is > 140 as some respondents identified as belonging to multiple groups.

Table 1
Survey question ecosystem service categories and specific ecosystem services.

Ecosystem service category	Specific ecosystem services
Recreation and education 	Dog walking Education (e.g. school trips, outdoor classes) Observing nature Picnicking/Barbecue Playing sports/running Relaxation/reflection Safety (e.g. from criminal/anti-social behaviour) Wild food (e.g. blackberry picking) Other (please state below)
Environment and climate 	Attractive appearance Carbon storage Low contamination levels (e.g. asbestos, heavy metals) Low flood risk Provision of shade/shelter Other (please state below)
Food, energy and other plant products 	Allotment gardening Growing biofuels Growing crops Other plant products (e.g. timber, materials for basketry) Other (please state below)
Nature and wildlife 	Bird biodiversity Insect pollinator biodiversity (e.g. bees and butterflies) Biodiversity of other insects and invertebrates Mammal biodiversity Plant biodiversity Reptile and amphibian biodiversity Other (please state below)
Suitability for development 	Absence of protected species (e.g. bats and newts) Ease of vegetation removal Ground bearing capacity (i.e. soil strength) Low contamination levels (e.g. asbestos, heavy metals) Low flood risk Other (please state below)

As some individuals tended to score all ecosystem service categories either high or low, and this precluded the identification of demand patterns, we first standardised the data by summing all scores given by an individual and calculating scores for each category as a proportion of this total. All analyses presented were then conducted using R (version 3.5.0 2018-04-23). Pearson correlation matrices were used to illustrate the relationships between the responses for categories and for specific ecosystem services of the survey, using the R package '*corrplot*' (Wei and Simko, 2017). We correlated the preference scores of different ecosystem services to see which were positively (synergies) and negatively (trade-offs) related. We also performed a cluster analysis on the ecosystem service preference scores to evaluate if there were certain groups of stakeholders with consistent preferences. This cluster analysis was performed using the R package '*factoextra*' (Kassambara and Mundt, 2017) for the different categories and associated specific ecosystem services. Additionally, one-way analysis of variance tests (ANOVAs) were conducted to compare the ecosystem service demands between stakeholder clusters.

3. Results

3.1. Correlation matrices

3.1.1. 'Development vs green benefits?'

The correlation matrices revealed a single major trade-off in the ecosystem service demand (Fig. 1 and Tables SM1 and SM2). This was between all of the services in the 'Suitability for development' category (Table 1), and all other service categories. These were significantly negatively correlated at the ecosystem service category level e.g. 'Recreation and education', 'Environment and climate', 'Food, energy and other plant products', 'Nature and wildlife' (Fig. 1a). The correlation between most other major ecosystem service categories was generally weak and non-significant, indicating that there was neither a strong trade-off nor synergy in demand for most services. The correlation matrix also demonstrates that the demand for most ecosystem services within a category (specific ecosystem services) (Fig. 1b) was strongly positively related, with particularly strong relationships between services found in 'Food, energy and other products' ($r = 0.75–0.88$), 'Nature and wildlife' ($r = 0.81–0.97$) and 'Suitability for development' ($r = 0.81–0.92$). When looking at specific ecosystem services, negative relationships were also found between the ecosystem services in 'Recreation and education', 'Environment and climate', 'Wildlife' and all ecosystem services associated with the 'Suitability for development' category. Particularly strong negative relationships were found between 'Suitability for development' and the specific ecosystem services of 'Education', 'Observing nature', 'Wild food' and 'Relaxation'. While the trade-off between development and all other services was by far the strongest trend in our survey, we also found negative relationships between both 'Sports' and 'Biodiversity' and 'Attractive appearance' and 'Biodiversity', across a range of taxa, possibly highlighting a demand for either managed parks or wild spaces. Furthermore, given the framing of the survey, it was notable that 'Carbon storage' had few strong correlations with the other services, with the exception of the 'Suitability for development' category services.

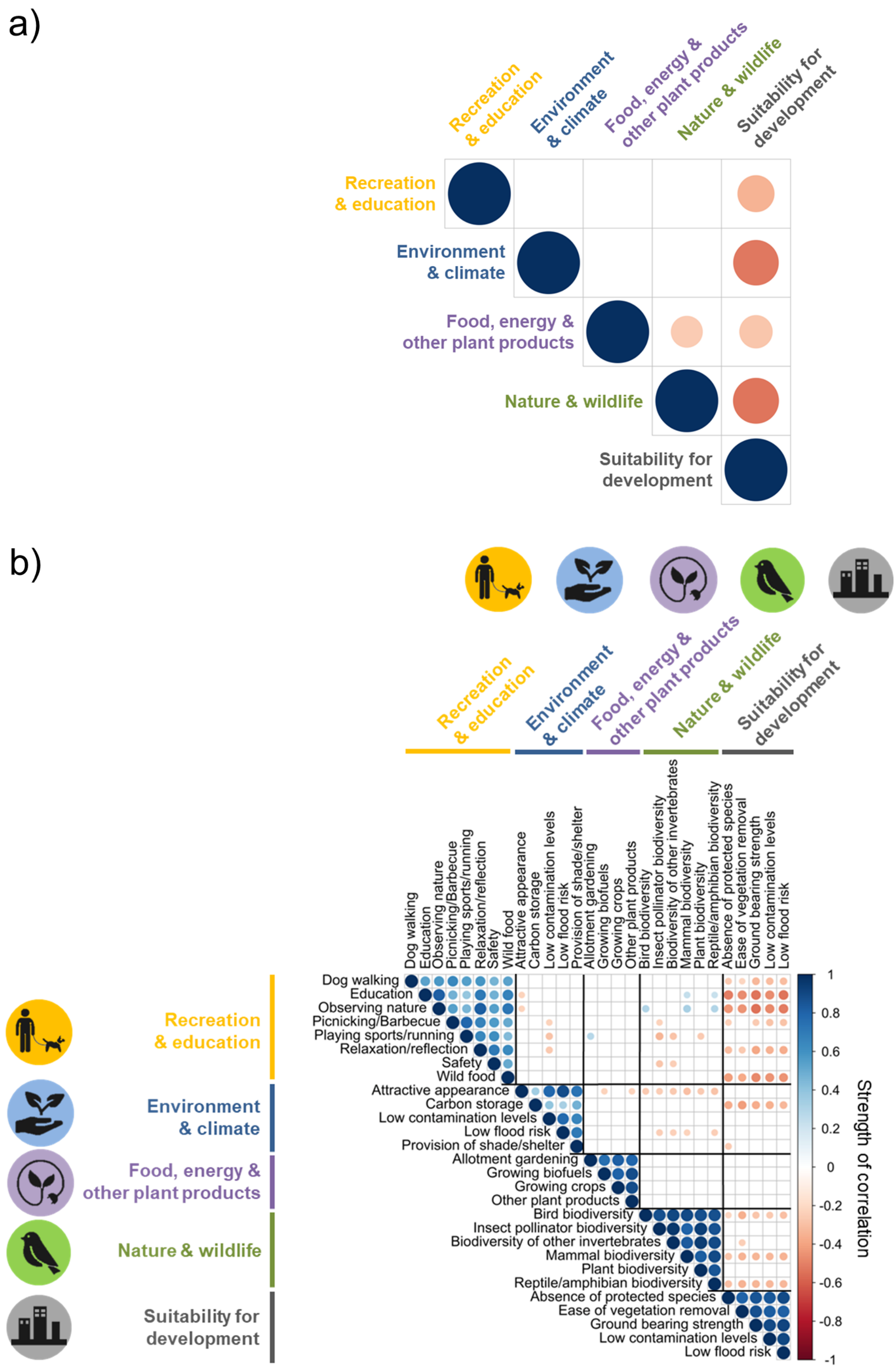

Fig. 1. a) Correlation matrix between ecosystem service category preferences (n = 140), b) correlation matrix between specific ecosystem service preferences (n values displayed). Note that the number of respondents for specific ecosystem services is a subset of the number of respondents for the categories as scores were assigned to specific ecosystem services only if the main category was weighted highly by the respondent (Category score ≥ 3). Only relationships with a significance of P < 0.01 are shown in the matrices.

a)

b)

	Dim.1	Dim.2
Recreation & education	0.42	**0.49**
Dog walking	0.42	**0.54**
Education	**0.69**	0.41
Observing nature	**0.75**	0.34
Picnicking/Barbecue	0.35	**0.65**
Playing sports/running	0.21	**0.70**
Relaxation/reflection	**0.56**	0.51
Safety	0.18	**0.57**
Wild food	**0.61**	0.44
Environment & climate	**0.46**	-0.09
Attractive appearance	**-0.15**	0.04
Carbon storage	**0.33**	0.05
Low contamination levels	-0.08	**-0.11**
Low flood risk	**-0.06**	0.06
Provision of shade/shelter	0.06	**0.09**
Food, energy & other plant products	0.01	**0.40**
Allotment gardening	0.02	**0.33**
Growing biofuels	-0.08	**0.27**
Growing crops	-0.10	**0.33**
Other plant products	-0.03	**0.28**
Nature & wildlife	0.58	**-0.61**
Bird biodiversity	0.62	**-0.65**
Insect pollinator biodiversity	0.50	**-0.77**
Biodiversity of other invertebrates	0.55	**-0.75**
Mammal biodiversity	**0.65**	-0.58
Plant biodiversity	0.52	**-0.74**
Reptile/amphibian biodiversity	**0.66**	-0.61
Suitability for development	**-0.86**	-0.08
Absence of protected species	**-0.76**	-0.21
Ease of vegetation removal	**-0.77**	-0.10
Ground bearing strength	**-0.83**	-0.20
Low contamination levels	**-0.80**	-0.21
Low flood risk	**-0.83**	-0.18

Fig. 2. a) Cluster plots across stakeholder preferences for all ecosystem service category and specific ecosystem service responses (agglomerative coefficient = 0.93) (Cluster 1, 111, Cluster 2, 29), b) coordinates and contributions of ecosystem service category and specific ecosystem service scores along the two dimensions, showing which ecosystem services are positively and negatively associated with the axis scores shown in (a). Services positively (green) or negatively (red) associated with one or the other dimension are indicated in bold.

4. Cluster analysis

4.1. 'There are two kinds of people: conservationists and everyone else'

The cluster analysis found that respondents separated into two cohorts along the first axis: a small 'conservationist' group highlighted in green, who had a high preference for services related to education and nature conservation (positively associated to the first axis, with strong preferences for specific ecosystem services in the 'Recreation & education', 'Environment & climate' and 'Nature & wildlife' categories), and a larger and less consistent group highlighted in grey, who valued services from the other categories (negatively associated to the first axis) (Fig. 2 and Figs. SM1-SM5. For reference, Fig. SM2 and SM3 illustrate cluster analysis for ecosystem service categories only, SM4 and SM5 illustrate cluster analysis for specific ecosystem services only). Of the respondents in the 'conservationist' cohort, 46% of them identified as belonging to the 'Ecology and Environment' sector, 33% of them belonged to the 'Academic' sector and the remaining 21% were in the 'General Public' (12%), 'Industry' (6%) and 'Local government' (3%) sectors (Fig. 2 and SM1). The respondents in the 'other stakeholder' cohort were more evenly distributed across the different sectors (Fig. SM1). The preference scores of the two cohorts were compared with ANOVA. The groups significantly differed in their preference scores for most services ($p < 0.01$ for 23 of the 33 services, see Table SM3).

The second axis differentiated between users who desired food-based services and recreation (positively associated to the second axis, with preferences for specific services in the 'Food, energy & other plant products' and 'Recreation & education' categories) and those who desired biodiversity-rich green spaces (negatively associated to the second axis, with preferences for specific services in the 'Nature & wildlife' category), again highlighting a distinction between stakeholders demanding more managed parks and those who prefer more 'natural' biodiversity rich spaces.

5. Discussion

The strongest trade-off identified was between 'development'-based services and all others, while there was an absence of strong synergies or trade-offs in demand between most other services. This highlights that stakeholders either prioritise 'development' or the other roles that a site might perform. Cluster analysis also revealed that there was a clear presence of two 'cohorts' of respondents: 'conservationists' and other stakeholders. Together, these results show that development uses and open or green space uses are polarised. Qualitative statements from the survey captured this trade-off with some respondents stating a desire for brownfield sites to become "a natural wildlife park where nature reclaims its territory", while others called for "sustainable housing development".

Considering the development vs green space tension, one respondent stated that: "Urban brownfield land is multifunctional and very important in nearly all the ways listed above, except development as this would potentially eradicate all of the other uses, or at least, we'd have to mitigate against the loss of uses." Another reflected that: "in my sector of planning for future development in local government, housing delivery trump(s) all so unless you can suitably convince government of the acute and chronic need to actually deliver truly sustainable development through improved strategic urban design to integrate ecosystem benefits with the urban landscape […] the focus will remain on housing and therefore at a detriment to the much-needed long term ecosystem benefits we require." Some noted, more optimistically, that "Brownfield sites can consist of a mix of ecosystem and development. If housing is being considered, this is important" and "Where allocated for development the temporary use of brownfield land for ecosystems services is entirely legitimate".

The fact that most ecosystem services were similarly preferable to most respondents gives further weight to claims around the desirability of multifunctional sites. This is particularly encouraging as an increasing body of work shows that where green spaces are managed to optimise a given environmental 'service', such as carbon storage, then they are most effective in achieving this if they also provide a broader suite of ecosystem services i.e. they are multifunctional (Leeuwen et al., 2010; Madureira and Andresen, 2014; Selman, 2009). In terms of different ecosystem services, the general lack of trade-off in demand between non-development categories suggests that most people would be happy with multipurpose spaces. In this case a challenge lies in determining if and how it is biophysically possible to create spaces with such a range of desired characteristics. Trade-offs could occur in supply, e.g. if the vegetation that supports biodiversity is deemed unattractive, and multifunctionality may ultimately be limited by what is physically achievable. Setälä et al. (2014) note, for example, that in relation to soil ecosystem services there are mismatches between the demand for different land uses (e.g. agriculture, green space) and the physical capacity for soils to provide certain services. From a practical perspective it is helpful to consider broader patterns of supply across urban spaces, e.g. different green spaces dedicated to the different ecosystem service demand bundles identified here, if aiming to minimise trade-offs and boost synergies. Hansen and Pauleit (2014) propose a conceptual framework for the assessment of multifunctionality from a social–ecological perspective, which assumes an imbalance of supply and demand and warns of the risk when the 'capacity of ecosystems to provide services is assessed detached from social questions of demand'. In order to reduce trade-offs and increase synergies in brownfield urban development, the views of a range of relevant stakeholders must be engaged. However, this study suggests that the wide range of preferences of a diverse stakeholder community can be simplified into heuristic categories, making general solutions more identifiable.

These findings are important in informing urban planning that engages in the development of brownfield sites, to improve the "ecological function of human-dominated landscapes" (Felson & Pickett, 2005). Even if ultimately developed, brownfield sites can promote a range of benefits and may be used as 'temporary' conservation or recreation spaces (Kattwinkel et al., 2011). Previous studies have found the 'when traded off individually with urban development, many environmental benefits (such as carbon storage) were insensitive to development' (Richards and Friess, 2017). It is possible that what people want from urban green spaces can at least in part be allied with the possibilities offered by 'development' spaces (Richards and Friess, 2017; Ziter and Turner, 2018).

The survey conducted here focused on brownfield sites and it is possible that this framing shaped the responses received; if we were looking at established parkland, for example, responses would have been different. Brownfield sites may carry connotations or expectations of future use based on previous development, and can be perceived as low value and even a source of disservices (e.g. as sites for antisocial behaviour, as there is a complex relationship between urban brown and greenfield sites and behaviour in urban spaces (CABE, 2004). Responses were also based on 'hypothetical' brownfield sites as imagined by our respondents, rather than grounded in particular types of site or location. Public perception and valuation of brownfields varies considerably, e.g. with factors such as successional age (Brun et al., 2018), and it may be that our results would have been different if we had surveyed users with reference to specific sites. Participation by a mix of urban and non-urban residents is also likely to have impacts, with respondents being more or less familiar with a range of urban environments. The 'services' ultimately contributed by potential development, e.g. affordable housing, shops, schools etc., was also hypothetical. Finally, social data and details including specific employment role and urban residence were not gathered, as this was not an initial aim of the survey, but may have been revealing in further disaggregating preferences across this cohort by other demographic factors.

6. Conclusions

Brownfield sites represent a relatively 'blank slate' in otherwise often densely developed urban areas, within which a wide range of ecosystem management options may be applied. Therefore, it is important to understand which services stakeholders demand from brownfield sites if we are to manage them appropriately. Our results demonstrate that there is a strong trade-off in demand for brownfield ecosystem services, which occurs between stakeholders who seek to 'develop' brownfield sites, and other stakeholders who seek services linked to green spaces. Within the latter group there was a secondary trade-off between those who sought more 'natural' sites characterised by opportunities to reflect upon nature and biodiversity protection and those interested in sites that were attractive and suitable for recreational activities such as sports. The latter trade-off was relatively weak suggesting that as long as the site is kept open and undeveloped then conflict over brownfield management is more likely to be driven by physical and biological limits and trade-offs, e.g. the contrasting services provided by mown and fertilized grassland and those of unmanaged forest and scrub (Paillet et al., 2010) than strongly contrasting patterns of demand among stakeholder groups.

On the basis of this survey, we conclude that multifunctionality can be sought from brownfield sites, and that demand for a range of services may be shared across diverse stakeholder groups. This multifunctionality may be achieved at a single brownfield site where biophysical constraints are absent, and all services respond positively to the same drivers, e.g. all services are high in semi-natural grasslands. Where biophysical constraints that generate trade-offs in ecosystem service supply are present, e.g. if naturally vegetated sites promote biodiversity and more open mown areas promote recreation services, multifunctionality will need to be achieved by generating in patches within a site, or across multiple sites (van der Plas et al., 2019). Further research is required to understand whether these results are more widely generalisable. It would also help to elucidate the social factors that underpin patterns of demand. A key challenge in leveraging these insights in brownfield site development is assessing which ecosystem service 'bundles' could be realised given the broader context of biophysical and economic trade-offs and how these can be minimised.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoser.2020.101074. All data created during this research are openly available at https://doi.org/10.25405/data.ncl.11771331.

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